ADAPTATION AND RESILIENCE TO DROUGHTS: HISTORICAL PERSPECTIVES IN EUROPE AND BEYOND

University of Strasbourg (France)

1st – 2nd June, 2017

BOOK OF ABSTRACTS
Edited by:
Carmen de Jong
University of Strasbourg

May 2017
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1. Narrative Sources for Reconstructing Droughts
OUTSTANDING DROUGHTS IN THE PAST
NIGHTMARE VISIONS OF GLOBAL WARMING

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Studying the past is the best way of obtaining an idea about the magnitude and severity of climatic low-probability, high-impact events that as result of global warming are expected to occur more frequently in the future. Droughts of implausible duration and severity belong to the most devastating possible consequences as is demonstrated by the case of the eleven-month long drought that occurred in Europe in 1540. Although the effects of this event on people and the environment were serious, the question needs to be raised whether today’s societies are less vulnerable to outstanding drought than those in the past.

This paper first outlines the extreme heat and drought of the year 1540 and its consequences on the environment, economy and people, distinguishing between its meteorological, hydrological, agricultural and socio-economic dimensions. The consequences are then compared to those of the outstandingly hot summer (June to August) 2003. Subsequent analysis of the impacts of the 2003 event exposes the vulnerability of present-day societies in facing such “ultimate” extremes. To conclude, some possible consequences of a present-day analogue case to 1540 are envisaged.

**Keywords:** droughts, past and present, global warming, extreme weather.
FAMINE AND DROUGHT IN JEREMIAH 14* AND JOEL 1-2* AND THEIR RECEIPTION IN EARLY MODERN EUROPE

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This paper takes the biblical texts in Jer 14:1-9.20-22 and Joel 1:1.10-12.17-20; 2:21-24.26a as a starting point. Both texts describe a drought and its impact on humans and animals. This depiction is followed by a lament using stylistic, thematic and structural elements characteristic of laments elsewhere in the Hebrew Bible. Both laments share the theological insight that Yahweh punishes his people because of their sins. At the same time the texts make clear that God can help the people and lead them out of the misery they suffer. Jer 14* and Joel 1-2* are thus impressive documents of how people in Ancient Israel coped with famine and drought.

The historical context of these two texts has long been debated. Recent paleoclimate research points to drier climate conditions during the first phase of the Persian Period (~ 530-450 BC). A precise dating of the texts based on these new scientific observations is not possible however. Even so, I will argue that these two laments, with their distinct vocabularies, share a common historical background when the memory of a drought was still vivid. Only in later times have drought, pestilences and war been put together and seen as one single instrument of God to punish his people (see also Dtn 28).

In a final part I will analyze how these biblical texts have been received in sermons in Early Modern Europe (e.g. Bußspiegel by Johann Erhard Cellius; Tuba Joelis by Johann Müller). The main questions will be how these biblical texts have been interpreted to cope with famine and inflation centuries later and how they were contextualized as an announcement of God’s punishment but also as a source of hope.

Keywords: Hebrew Bible, Book of Prophets, lament, coping strategies, Reception History.
FOR A HISTORY OF DROUGHT PHENOMENA IN CALABRIA BETWEEN THE MIDDLE AGES AND THE MODERN AGE: THE CONTRIBUTION OF ECCLESIASTICAL AND HAGIOGRAPHICAL SOURCES

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Calabria is a region of Italy whose history has often been marked by natural events. Earthquakes, floods, droughts and sudden meteorological extremes have struck with varying degrees of tragedy, affecting its social, cultural, economic and demographic context in a manner which is probably more profound and dramatic than wars or political upheavals. Historians exploring Calabria’s past have rarely considered the methodological approach and the fascinating fields of study offered by environmental history, typically preferring inspirations offered by traditional historiographical criteria. It is also important to take into account the meager reservoir of useful historical sources for the reconstruction of Calabria’s history between the Medieval Period and the Modern Age, particularly with regard to events, landscapes and aspects of the natural environment which have shaped the daily lives of its inhabitants.

Reconstructing a narrative from the specific perspective of droughts that occurred in Calabria is therefore quite a challenging task. A valuable aid in filling this gap in history may be derived from the rediscovery and reinterpretation of various hagiographic materials and more generally from medieval and modern church archives. This paper intends to propose a reflection on how to establish the historical reconstruction of droughts that occurred in Calabria using hagiographic and ecclesiastical sources, such as accounts of miracles, pro-pluvia processions and inventories of goods and agricultural produce governed by ecclesiastic authorities.

**Keywords**: Hagiography; drought; Calabria; pro-pluvia processions; Middle Ages.
DROUGHT IN LATE MEDIEVAL ENGLAND.
ITS IMPACT ON AGRICULTURE AND ITS ROLE IN THE
FORMATION OF MAJOR PLAGUE WAVES

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Using narrative and administrative documentary sources from late medieval England this paper considers the impact of drought on the agricultural and pastoral sectors as well as on human health. On the basis of the length of the grain harvest, which largely depended on precipitation totals and frequency, a precipitation index for late summer and early autumn is developed for eastern England; independent documentary evidence is used to confirm and supplement the data. Whereas narrative sources are often silent on drought, except for the most severe cases, manorial accounts – a source type recording the strategy, profits and expenses of seigniorial agriculture – supply detailed information on dry conditions during the growing season. Drought could, if protracted, diminish the productivity of grain cultivation and raise the grain price, but it was by no means as dangerous in England as excess precipitation. However, its potential impact on human health was much more profound. It provided ideal conditions for gastro-intestinal infections, but more importantly it played a significant role in major plague outbreaks. After the First Pestilence the disease continued to swell to epidemic proportions at intervals and in late medieval England these recurrent outbreaks resulted in a negative demographic long-term trend and population dynamics became mortality-driven. The combination of the series of late medieval English major plague outbreaks with regional climate data reveals that contrary to general belief, major plague outbreaks mostly did not coincide with harvest failure, chaos and widespread malnutrition once Yersinia pestis had established itself on the British Isles. Instead they were embedded in a complex sequence of specific meteorological conditions in the seasons before and during the plague outbreak, the most important determinant being hot and dry weather during the summer half-year of the outbreak itself.

Keywords: Middle Ages, England, precipitation index, agriculture, plague
During the second half of the fifteenth century a year of outstanding heat and drought occurred in Europe. In 1473 the spring season started with an extraordinarily hot spell in Europe. This heatwave in turn favoured accelerated phenological development. In the summer and autumn of the same year temperatures were exceptionally hot and furthermore it was very dry. In many places the harvest was brought in remarkably early and there was an abundance of high-quality wine. Reports even exist of fruit trees starting to blossom for a second time in the autumn. Nevertheless, the heat and drought in 1473 also had considerable impact on the natural environment and brought damage to agriculture and society, such as drying of springs, wildfires at uncommon places, cattle suffering from hunger as well as losses in grain, fruit and vegetable production.

This paper aims to analyse the weather conditions of 1473 in Europe, as well as their impacts on society by answering the following questions: What was the magnitude and sequence of heat and drought in 1473? Were there any differences between the various regions in Europe? To what extent were European societies vulnerable to extreme drought events in the second half of the fifteenth century? What impacts did weather have in Europe during the year under examination? Are regional differences traceable?

In order to respond to these questions a large number of historical sources, such as chronicles, annals and accountancy books, mainly from France, the Low Countries, the Holy Roman Empire and England will be examined and compared to the results of tree ring and speleothem analyses.

A paper by Christian Rohr concerned with locust invasions after 1473 and 1540 and a paper on the 1540 drought by Christian Pfister are associated with this presentation.

**Keywords**: historical climatology, drought, vulnerability, weather impacts on society
DROUGHTS IN THE CZECH LANDS BETWEEN AD 1501 AND 2015

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Droughts represent one of the most important hydrometeorological extremes in the Czech Lands. Following the first credible report of the dry winter of 1090/1091 in the Cosmas “Chronicle of Czechs“, rich evidence from dendrochronological data, documentary sources and instrumental meteorological measurements provides a comprehensive overview of the spatio-temporal variability of droughts from AD 1501 onwards. The paper first presents information from the three above-mentioned data sources with examples related to meteorological, agricultural and hydrological droughts and their impacts. Continuous variability in drought severity is expressed via four commonly used drought indices: the Standard Precipitation Index (SPI), the Standard Precipitation Evapotranspiration Index (SPEI), the Z-index and the Palmer Drought Severity Index (PDSI). Long-term drought chronologies in the period between AD 1501 and 2015 are compiled from temperature and precipitation reconstructions based on documentary data and instrumental records. They are further evaluated with respect to the (Central) European context placing particular attention on extremely dry years, decades as well as longer time periods. Synoptic triggers of drought episodes and a list of exceptionally dry years are presented for the instrumental period from 1804 onwards including the particularly disastrous drought of 1947. Other important reasons for droughts are presented. After discussion of the results, the new project of the Czech Science Foundation (No. 17-10026S) running from 2017–2019 on “Drought Events in the Czech Republic and their Causes” is presented.

Keywords: documentary data – drought indices – drought reconstruction – disastrous droughts – drought forcing – Czech Lands.
“THE SEASON HAS BEEN AN UNUSUALLY DRY ONE”:
PERSPECTIVES ON NINETEENTH CENTURY DROUGHT IN
SOUTHERN AFRICA IN DIFFERENT HISTORICAL SOURCE TYPES

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Single-year and more protracted drought episodes posed significant challenges for agrarian communities across southern Africa during the nineteenth century, and hence are widely recorded in a variety of historical documents. However, the ways in which droughts are articulated, and the focus of individual accounts, varies considerably between different authors and historical source types. In this study, we draw on a range of documentary sources – specifically letters, reports, newspapers and diaries – to explore the varying narratives associated with three droughts (those of 1861-63, 1876-79 and 1895-97) that affected large areas of the southern African summer rainfall zone. Our analysis spans five case study areas – present day Mpumalanga and KwaZulu-Natal (South Africa), Botswana, Lesotho and Malawi – investigated as part of various interdisciplinary projects funded by the British Academy, Leverhulme Trust and UK Natural Environment Research Council. We explore issues including (i) how specific drought events are framed, and (ii) what is and is not reported about individual droughts across different sources. We conclude that different source types in the subcontinent may be more or less appropriate for addressing the specific objectives of historical climatology, particularly in relation to historical drought. Sources such as weather diaries, newspapers and colonial reports (e.g. ‘Blue Books’) are rich in observations suitable for the reconstruction of temporal and spatial patterns of weather and climate, as well as climate-related natural disasters. In contrast, letters and personal journals, especially those written by missionaries, provide narratives through which to investigate the vulnerability of past societies and economies to climate variations, and to explore past discourses and social representations of climate.

**Keywords:** drought history; southern Africa; nineteenth century; source criticism.
18TH CENTURY DROUGHTS IN PORTUGAL

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Droughts are meteorological extreme events that have significant impacts on individuals and societies. Records of their impacts and/or measures taken to avoid them have been retrieved from different documentary sources in the frame of the KlimHist Project. The database constructed within this project gathers more than 3000 entries which permit to reconstruct different extreme weather events. Individual sources, including memoirs, books, poems and newspaper articles and institutional sources including civil and ecclesiastical sources are used.

In this presentation we present evidence of 18th century droughts which occurred in two Portuguese regions: NW Portugal (data mostly from Oporto and Braga) and “Central Portugal”, (e.g. the area between Lisbon and Évora). Evidence refers to water scarcity (mainly due to low rainfall amounts), insufficient water resources (and low river flows), as well as consequences of lack of water in agriculture, animal husbandry, economy, health and mortality rates.

The main drought periods occurred in 1714-15, 1734-38, 1750-57 and 1779-83. Some significant drought episodes will be reconstructed in detail, mainly those when pro-pluvia ceremonies took place. Most droughts occurred in spring, winter and summer, although there are regional differences: NW Portugal is mostly associated with summer droughts whilst Central Portugal (where it hardly ever rains in summer) attracts with spring and winter droughts.

Keywords: droughts, 18th century, documentary evidence, Portugal.
LOW WATERS, A COMPLEX INDICATOR FOR CLIMATE HISTORY. MATERIAL AND METHODS FOR EVALUATING THE MAN-INDUCED COMPONENT OF WATER SHORTAGES (LATE 18TH - EARLY 20TH CENTURY)

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Over the past two decades studies on climate history have contributed to improving knowledge on past droughts, particularly through the study of pro pluvia rogation ceremonies (e.g. Martin-Vide and Barriendos 1995, Piervitali and Colacino, 2001, Garnier, 2010). Simultaneously, other authors have proposed studying social responses to past climatic events as well as their economic or agricultural impacts (Pfister, 2010). As such, since climate history relies heavily on written sources based on specific societal reactions such as mentions or complaints of extreme climate events or catastrophes these approaches are not independent from each other. For droughts, written sources describing low flows or exceptional drying of streams are indisputable indicators of periods of low precipitation. However, deducing the severity of an event or comparing dry episodes is less obvious. We postulate that the sensitivity of a society to such phenomena may fluctuate over time, due to its stronger or weaker dependency on water flow, which in turn depends on the way in which it exploited water resources, or even to what extend it exerted pressure on water resources and exacerbated the situation. For example, in the Cévennes (Southern France) some crises caused by water scarcity during the nineteenth century had an incontestable social component (Jacob-Rousseau, 2005). In this context, a better knowledge of the hydrological consequences of agricultural or industrial water exploitation in the past could shed a critical light on useful sources in climate history. It could also provide the basis for discussing results obtained from modelling reconstructed low-flow periods.

The purpose of this paper is to present research we initiated on the pressures exerted on water resources in the past (late 18th-early 20th centuries) for various catchments in south-eastern France. We will present a critical analysis of archival documents, which in France can be addressed at different spatial or temporal resolutions including statistics on industrial or agricultural water use, agricultural statistics or cadastral information. We will then demonstrate which type of approaches and data processing is appropriate for developing indicators both in order to identify real pressures and to evaluate how water withdrawal could have influenced low flow in the past. Finally, we will present some case studies on the temporal and spatial impacts of droughts in watersheds. This will enable a critical comparison of the geographic context and the textual information.

Keywords: droughts, water resources, sources, perception of weather
Even if the symposium “Adaptation and Resilience to Droughts: Historical perspectives in Europe and beyond” does not seem to include North America, it is most likely that the drought that occurred in the United States just after the market crash of 1929 is a textbook example. Indeed, those ten years of drought and their impacts on agricultural systems and peasant societies of Kansas, Colorado, New Mexico, Oklahoma and Texas are well documented. In these regions with a rough climate – due to weak rainfall, very cold winters and scorching summers - the slightest deviation of rainfall from normal becomes problematic for rain-fed agriculture.

That was the case during the 1930’s. Therefore we attempt to put the views of contemporary artists of that period into perspective.

- A regionalist painter, Alexander Hogue, created a series of paintings between 1933 and 1936 representing the disaster which tossed thousands of farmers out onto the roads towards the West.

- The famous novelist, John Steinbeck, published The Grapes of Wrath in 1939 which was adapted for the big screen by John Ford in 1940, depicting the tragic destiny of a farming family that was forced to flee from Oklahoma towards a supposed El Dorado in California due to the lack of rainfall.

- A photographer, Arthur Rothstein, captured the figures of the victims of the sand and dust storms with his camera between 1931 and 1946.

The American Great Plains with fertile cultures and green grasslands, which represented the model of liberty and utopia, where the one who undertakes must succeed, becomes dust territories of relegation, even exclusion of the small ones. Thus the drought is the “climatic trigger” of a changing economic, social and cultural model.

**Keywords**: USA, paintings, literature, photography, dust bowl.
DROUGHTS IN HISTORICAL TIMES IN POLISH TERRITORY

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Climate change is not only a key environmental, social and economic issue but also has major political impacts. The impacts of climate on a country’s economy are increasingly recognized and much attention is given to them both at the global scale as well as by individual national governments.

Due to the significance of the problem it has been necessary to develop a strategy for minimizing potential negative impacts, which may result from global warming both at the regional and local scales.

“Proxy” data often inform us about dry years and dry seasons and hot periods without precipitation. Analysis of historical documents allows the extraction of the years that have experienced prolonged periods of high temperatures and rainfall shortage. Weather phenomenon defined as droughts can be defined as extreme events. This information has been very helpful for the process of indexing and thus to reconstruct the course and intensity of climatic events in the past. The analysis covers the period from the year 1000 to modern times. Due to the limited information from the period of 1000-1500 the authors focused primarily on the period from 1500 to 2015. Analysis of the collected material has allowed the development of a highly precise temporal reconstruction of the possible occurrence of dry periods over the Polish territory.

**Keywords:** atmospheric (meteorological), soil and hydrological drought, analysis of Proxy data, reconstruction, digitalization and analysis historical data, monitoring of extremes.
2. Past Variability of Droughts
DRIER - DROUGHT RECONSTRUCTIONS, IMPACTS, PROCESSES AND RESILIENCE SINCE 1500 FOR THE GERMAN SOUTH-WEST

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DRIeR is a project of the “Wassernetzwerk Baden-Württemberg”, which started in June 2016 and will run until 2021. The research consortium consists of the Universities of Freiburg, Heidelberg and Tübingen. DRIeR intends to improve the understanding and characterization of droughts and their impacts. The network partners investigate drought as a natural hazard as well as the social and ecological vulnerability to drought with a number of different approaches. DRIeR combines climate reconstruction from historic records and tree ring proxies for the long-term history, water quality and quantity indicator-to-impact analysis and statistical modeling for the instrumental record, ecological experiments as well as hydrological modeling and land surface modeling for different land uses for simulation and scenario generation. Together with a comparative legal and environmental policy (governance) analysis for the recent past in Baden-Württemberg and regions that are already experiencing and adapting to drought, the project will elucidate the complex interactions of climate, environment and society in periods of drought and water shortages at a range of temporal and spatial scales. DRIeR also aims to increase the visibility of the different aspects of drought through the creation of a common drought information and collaboration platform (tambura.org), which will act as a center of the network and will facilitate the analysis and derivation of suitable indicators and approaches for drought management planning in the region.

First of all, reliable long-term reconstruction of dry periods in Baden-Württemberg based on historical records and their impacts on agriculture (harvest yields), economy and society from 1500-2015 are presented. There are so far more than 1.000 written sources indicating dryness and droughts collected, coded and transferred into the collaborative research environment tambora.org. In addition, from 1800 onward, early instrumental readings of temperature and precipitation were compiled. These instrumental readings were used to evaluate the index we have built from the written sources ranging from -3: extremely dry to +3: extremely wet. Therefore the well-established SPI (standardized precipitation index), STI (standardized temperature index) and SPEI (standardized precipitation-evapotranspiration index) were calculated for the 15 time series. The stations were clustered to obtain the best significance for the whole research area and then tested against the harvest data of pasture for the time between 1865 and 2015, which shows a high correlation of pasture-yield failures and dryness during the growth period. In correlating the index of the written sources with the SPI we obtained good correlations between 0.70 and 0.87. A third index was derived from the tree-ring data between 1500 and 2015. So, in total we used three independent indices to identify dry periods between 1500 and 2015, which overlapped since the mid of the 19th century. Numerous extreme events and dry periods have been identified (likewise 2015, 2003, 1976, 1949, 1921, 1834, 1718, 1631 or 1540) as a reliable basis for further risk related analysis. The data stored within tambora.org is visible and accessible for interested scientific community, stakeholders and the public.

Keywords: dryness, drought, Baden-Württemberg, long-term reconstruction.
SHORT-TERM FLUCTUATIONS OF PERIODS WITH CONSECUTIVE DRY DAYS IN THE CONTEXT OF CENTENNIAL VARIABILITY IN THE EASTERN CARPATHIAN FORELAND

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Previous studies on the centennial variability of annual and seasonal precipitation in the Eastern Carpathians show that the last decade is remarkable for its short-term fluctuations (3-4 and 10-12 years) contributing to the idea of recurring regional atmospheric circulation. The phases are common at the beginning of the 20th and the 21st centuries. These cycles are typical for drought events as well. In this context, the Eastern Carpathians forelands deserve special attention since they also represent the most continental part of the Carpathian region prone to extreme precipitation events. Their location plays a role in balancing hydro-meteorological processes such as active moisture transport influenced by rapid thermodynamic processes and heterogeneity in exposure to circulation.

Periods with consecutive dry days (CDD) are used as an informative index to explore drought dynamics since they reflect the intensity and variability of circulation patterns over complex topography. In general, over the last two decades these periods have increased compared to the climatological norm of 1961-1990. This peculiarity already occurred at the beginning of the 20th century but was later compensated by a steady increase in atmospheric precipitation over the first half of the century. At the beginning of the 21 century, the mean duration of dry periods in the region became similar to those over the Ukrainian steppe (12-16 consecutive days). They were followed by an intensification of zonal circulation and a 56% increase in the occurrence of anticyclones. Since precipitation in the region is limited to torrential short-duration rainfall this primarily impacts the vegetation period. For the rest of the year, drought periods essentially occur during the warm season and are distributed uniformly over the months of April-July and August-October. The latter period is experiencing longer CDDs of increasing reoccurrence interrupted by more continuous precipitation events. Another drought peculiarity is the appearance of dry winds reinforced by thermodynamic slope processes that are atypical for the adjoining flat area.

Centennial analysis of CDDs reveals two dry and two wet years per decade. The beginning of the last two centuries shows an increased reoccurrence of these years per decade. Besides, the most persistent CDDs have shifted in summer from August to July and in autumn from October to September. The distribution during these years is chaotic but the consecutive reoccurrence of such years may be another sign of transformation of regional atmospheric patterns. Altogether, the annual, seasonal and monthly distribution of CDDs within the centennial dynamics may serve an indicator of centennial drought variability. Moreover, while analysed in the continental foreland, short-term fluctuations of the parameter improve our understanding of the role of complex terrain in balancing hydro-meteorological processes.

Keywords: period with consecutive dry days, foreland, Eastern Carpathians, short-term fluctuations, centennial variability.
This research presents a study of extreme low flow events that occurred from 1871 onwards in a large number of near-natural catchments in France. It aims at assessing and comparing their characteristics to improve our knowledge on historical events and to provide a selection of benchmark events for climate change adaptation purposes. The historical length of streamflow observations is generally limited to the last 50 years and therefore covers too small a sample of extreme low flow events to properly explore the long-term evolution of their characteristics and associated impacts. In order to overcome this limit, this study takes advantage of a 140-year ensemble hydrometeorological dataset over France based on: (1) probabilistic precipitation and temperature downscaling of the global Twentieth Century Reanalysis over France (Caillouet et al., 2016a), and (2) continuous hydrological modelling based on high-resolution meteorological reconstructions as forcings over the whole period. The resulting SCOPE Hydro dataset provides an ensemble of 25 equally plausible daily streamflow time series for a reference network of more than 600 stations in France over the 1871-2012 period.

Extreme low-flow events are identified using a combination of a fixed threshold and a daily variable threshold. The procedure is applied to the 25 simulated time series as well as to the observed time series in order to compare observed and reconstructed events over the recent period, and to characterize in a probabilistic way unrecorded historical events. A spatial matching procedure at the scale of France is then developed in order to spatially assemble local extreme events into the same spatio-temporal event. After these steps, an event can be studied at the local or national scale through its spatial extent, duration or severity characteristics in a probabilistic setting (Caillouet et al., 2016b).

This work identifies past and little known exceptional extreme events (1878, 1893, 1942-1949) or recent but poorly documented events (1972, 1978, 1985) besides well-known events (1921, 1976, 1989-1990, 2011). The evolution of these events since 1871 shows that an increasing part of the French territory is affected by extreme low-flow events since the 1940s. Finally, a good coherence is found between reconstructed events and narrative sources on historical droughts. For the first time, extreme low-flow events are described in a homogeneous manner over 140 years for a large set of near-natural French catchments, enabling detailed analyses of the effect of climate variability and anthropogenic climate change on low-flow hydrology.

**Keywords:** High-resolution ensemble reconstruction, extreme low-flow events, event characterization and comparison, spatio-temporal extent and dynamics.
VARIABILITY AND SPATIAL EXTENT OF DROUGHT(S) AT THE BEGINNING OF ANTIQUITY IN NORTH-EAST FRANCE.
CONTRIBUTION OF SOIL ARCHIVES TO SCARCE NARRATIVE DATA

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A climatic event during the 1st century A.C. called the Petit Optimum Romain (POR or Small Romain Optimum) has been highlighted by various paleo-climatical approaches (Magny, 1995, Bravard, 1997 and Holzhauzer et al., 2005). For this historical period, narrative archives are very rare and limited to general texts describing for example extreme geologic phenomena (volcanic eruptions) or military movements. Some authors (McCormick et al., 2012, McCormick, 2013) managed to characterize a stable, hot and wet climate, profitable to the Roman expansion. However, few texts reveal the exact extent and the local variability of this general climatic period. In north-eastern France (Alsace, Lorraine), soil-sedimentary observations carried out in the frame of rescue archaeology bring to light desiccation features situated in loamy clays bordering wet areas and dating from the end of the Iron-Age to the Early Middle-Age (Gebhardt et al., 2014, current work). Also, during the 1st century A.C., archaeology reveals the conquest of humid areas with, for example, the construction of buildings and tracks or drainage for agriculture development. This environment was abandoned towards the 4th century AC.

Geo-archaeological and archaeological data can be completed by paleo-environmental proxies providing more or less direct indicators of the climatic limits of ecosystems and in particular past drought events. Even short and intense droughts can have strong impacts on ecosystems since they are capable of changing the vegetation. The evolution of the specific composition of an environment can be estimated by pollen analysis, with more or less spatio-temporal precision depending on the quality of the pollen assemblages (Magny, 1995). Moreover, a strong drought renders the environment more sensitive to the disturbance of fire, whether natural or anthropogenic. Soil-charcoal analysis and dating can highlight drought events, for example by connecting "peaks caused by local fires" with socio-cultural data and / or climatic events (Robin and Nelle, 2014). Such approaches have been carried out in Germany and are in progress in the northern Vosges mountains.

This presentation will therefore attempt to demonstrate in how far soil archives, paleo-environmental studies (paleo-pedology, geomorphology, pedo-anthracology) and archaeology can be of invaluable help in supplementing narrative data for the characterization and localisation of historic climate-related events.

Keywords: Soil archives, Antiquity, Drought, North-Eastern France.
DROUGHTS AND LOW FLOWS IN THE MOSEL RIVER CATCHMENT SINCE THE MIDDLE OF THE 19TH CENTURY

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Droughts originate from long periods of below average precipitation. This precipitation deficiency, which might be called a meteorological drought, can have repercussions on different components of the hydrological cycle (soil moisture drought, hydrological drought, etc.) and on human activities (socio-economic drought). In this presentation we study hydrological droughts that have affected the Mosel catchment since the middle of the 19th century. These events produce severe low flows and can hence be analysed via stream flow. However, hydrometric data are rarely available before the 1950s. Fortunately, climate data records (temperature and precipitation) cover longer time series and can thus be used to reconstruct past low flows on the basis of hydrological modelling. Drought intensity and duration will be characterized from drought and low flow indices in order to create a classification in terms of severity.

The origin and development of hydrological droughts will also be analysed. Since relations between precipitation deficiency and low flows are nonlinear other factors have to be considered such as the physical characteristics of the catchment, antecedent conditions and anthropogenic pressure etc.

Lastly we will focus on drought impacts on human activities and measures that have been taken to anticipate and reduce the vulnerability to drought hazard.

Keywords: hydrological drought, historical low flows, modelling, Mosel basin.
This paper presents the reconstruction of droughts that have affected Alsace, France mainly between the XVII and XIXth centuries. It is based on research carried out in the frame of an IDEX postdoc at the University of Strasbourg focussing on adaptation and resilience to historical droughts across all seasons. Major drought episodes will be studied and particular attention will be drawn to the difficulties in determining the origins of certain droughts. Even if various indices from historical sources allow the determination of a dry episode (deficit of precipitation, low water levels etc) is it really possible to precisely distinguish between anthropogenic water abstraction and a natural hazard when our ancestors are speaking of a “drought”? Here a scientific confrontation is attempted between what is a “pure” natural hazard (lack of rainfall) and the competition for water resources which becomes particularly strong in the Vosgian valleys in pace with industrial development. This question can be answered with a certain degree of accuracy when comparing qualitative data (mentioning of droughts and various associated impacts in narrative sources) and quantitative data (first measurements and pluviometric observations). Can droughts sometimes be man-made, the precipitation deficit being only a “climatological trigger” in the words of Emmanuel Le Roy Ladurie? It will also be outlined how societies have responded and how dams put into place in the formerly glaciated Vosgian lakes in the 19th century have helped both in providing drinking water and water diversions to prevent rivers from drying up during low flows, maintaining industry (mills), summer irrigation as well as decreasing floods.

Keywords: droughts, historical climatology, water, adaptation, Alsace.
3. Adaptation and Resilience to Droughts
VULNERABILITY AND RESILIENCE TO DROUGHTS
IN THE NARRATIVE SOURCES (12TH – 14TH CENTURIES)

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This paper focuses on narratives of droughts provided by chronicles and gesta of the XIIth and of the XIIIth centuries with special attention being paid to the cultural analysis of such texts. Based on an in-depth analysis of the main collection of sources available at the European scale (MGH, Rerum italicarum scriptores, Recueil des historiens de la Gaule et de la France, etc.), common thoughts and attitudes towards such kinds of events are investigated in view of a total history. I wish to discuss firstly, the role of droughts within the natural spectrum of other meteorological events mentioned in the chronicles. They were not commented on as much as wet meteorological events (i.e. rainy summers, storms, etc.), which certainly speaks for a specific perception of social vulnerability towards climatic threats in the Middle Ages. Secondly, I wish to investigate the emotional perception of extreme drought events, through the analysis of the vocabulary of the chroniclers. Finally, I will try to discover from the sources what the real impacts of these events were on society (mostly in terms of food supply and epidemics) as well as the range of solutions put into place to cope with hardships. Ultimately, I will interrogate the resilience of the XII-XIIIth century’s society towards droughts.

Keywords: chronicles, narrative sources, meteorological events, droughts, Middle Ages.
Within the current context of global warming an increase in drought intensity and duration, particularly of meteorological droughts is generally expected. Both in term of land management, (re)construction of effective memory of these events and adaptation of human societies, knowledge and analysis of droughts over the long term is fundamental. The present study focuses on Western France, from Brittany to Gascony, between the fourteenth and eighteenth centuries. The temperate climate is characterized by its proximity to the Atlantic Ocean, usually giving rise to mild and moist weather. Occasionally a stationary anticyclone generates rainfall deficit causing hot weather, warm and dry winds and possibly droughts.

This research aims to:

1) Analyse historical documentation of the history of droughts in Western France and create an inventory of documented records. Narrative sources, account registers, records of city deliberations – amongst others through pro-pluvia processions records – etc may contain information on droughts. However, the gap between the original production of documents and those reaching us is considerable. These documentary shortcomings are mostly due to historical contingencies such as religious wars, the French Revolution and archival disasters such as the fire of the Chamber of Accounts in Paris in 1737 that destroyed almost all the archives of the city of La Rochelle. These gaps hamper comprehensive drought surveys.

2) define, through cases studies such as 1305, 1414, 1493, 1547, 1578, 1604-1605, 1639, 1706, 1785..., the physical characteristics of droughts and their agricultural, "environmental" (water bodies, soil, vegetation) and human impacts. For instance, May 1547 marks the beginning of an important meteorological drought in the West of France. Southern Brittany, Anjou, Poitou and Touraine were affected particularly strongly. The lack of precipitation quickly led to a hydrological drought. Rivers, including the Loire, dropped so low that it was impossible to sail them. Nantes and its inhabitants suffered particularly strongly from supply difficulties. Attics and shops are “male fourniz et garniz’ (poorly stocked and filled).

3) query perceptions and representations, memories and reactions by population and authorities towards droughts. For example, in the marshes of Vix contrebot, violent conflicts existed between owners. During droughts, some could easily divert watercourses and cultivate “foins et pacages passablement bons (fairly good hay and pasture) whilst others could only produce “bois et rozeaux (wood and reeds). In 1780, the intendant of Poitiers ordered in the general interest of the public to construct a sliding gate to improve water management.

Based on existing archival records and narrative sources, this historical approach provides the necessary time scale for the study of catastrophic phenomena. In doing so, it can make a valuable contribution to the prevention and management of natural hazards today.

Keywords: Little Ice Age, West of France, drought, historical documents, societies’ reactions.
THREE CENTURIES OF VULNERABILITY AND ADAPTATION TO DROUGHT IN THE ZAMBEZI-SAVE AREA OF SOUTHERN AFRICA, 1500-1830

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Rural farming communities in sub-Saharan Africa are often considered amongst the most vulnerable to future changes in rainfall. Most studies in the contemporary development literature, however, are written in ignorance of adaptation to drought in this region in the pre-1890 (‘pre-colonial’) world, and of historical differences in resilience and vulnerability. This paper attempts to address this empirical scarcity through a comparative study of adaptation to drought over a three-century period (1500-1830) in the area between the Zambezi and Save rivers in southeast Africa. Specific focus is lent to understanding spatial differences and temporal changes in vulnerability, and to tracing the spectrum of adaptation strategies pursued by different communities in this region over time. This long-run assessment is then combined with information on the severity and human impacts of historical southeast African droughts in order to evaluate the key factors that determined long-term resilience.

Research for this paper is based predominantly on documentary records relating to African society, in particular Portuguese early colonial records, missionary correspondence and travel journals, together with paleo- and historical climate records. Systematic analysis of these sources reveals stark differences in vulnerability and adaptation upon Portuguese-African contact in the sixteenth century. African communities under the influence of the interior state systems, for example, maintained a diverse food system, held access to social networks, and practiced a variety of local level coping strategies, whereas those on the banks of the Zambezi were almost exclusively reliant upon gathering as a buffer to drought. This picture nevertheless underwent considerable change over the next two centuries. The progressive erosion of African state power by the Portuguese and persistent civil war, as well as a decline in livelihood opportunities, resulted in a gradual impoverishment of the interior states, which was matched by loss of adaptive capacity and resilience in times of drought. By contrast, those areas of the Zambezi under the direct jurisdiction of Portuguese settlement actually recorded decreases in exposure to drought through the move towards large estates (prazos) and resultant agricultural diversification, which served to increase resilience to low-magnitude drought. However, this diversification masked more systematic vulnerabilities, so that when severe and protracted drought combined with violence and an increase in slave raiding on the Zambezi in the late-1820s, adaptation strategies broke down and led to large-scale population movements.

Keywords: drought responses, southern Africa, livelihoods, diversification, social networks.
LONG-TERM CHANGES IN WATER GOVERNANCE REGIMES AND DROUGHT ADAPTATION. A CASE STUDY IN THE METROPOLITAN REGION OF BARCELONA, NE SPAIN (1600-1870s)

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In order to understand historical trajectories of adaptation to hydro-climatic dynamics it is necessary to review the range of responses that have been developed by past societies for coping with them. Shedding light on the linkages between such responses and the institutional context in which the events occurred can also reveal the factors that historically have shaped, enabled or constrained adaptation actions. This study aims to examine the co-evolution between municipal responses to recurrent droughts and long-term changes in water governance regimes. The present study focuses on adaptation at the municipal scale. Despite the fact that local authorities represent key agents in drought governance and are today pressed to play a more significant role in adapting to climate change, their changing contribution to adaptation over the past few centuries has been scarcely examined.

Our research is based on a case study in the municipality of Terrassa, nowadays an important sub-centre of the Metropolitan Region of Barcelona (NE Spain). We cover the period ranging from the early seventeenth to the late nineteenth century and therefore extending from early modernity to the establishment and consolidation of a liberal political and economic system of the Spanish state. We use both archival research and a literature review to elaborate our analysis. For the archival research, main documentary sources include series of town council minutes and factitious series of documents from local and regional governance agencies (e.g. correspondence, petitions and public works files). We also review the local water company's collections, court proceedings and published minutes from the regional government. Finally, this multi-source set of primary data is complemented with local and regional instrumental series of precipitation and graphic material such as historic maps and photographs. Regarding the literature review, we select secondary sources informing about the changes in water governance regimes that occurred in Spain, and particularly in the NE region of Catalonia, during the period from 1600 to 1900.

The results from the present study are organized in two steps. Firstly, we identify the main phases in water governance regimes throughout: i) the pre-industrial phase (1600-1720s), ii) the transition phase (1720s-1808), and iii) the modern phase (1808-1870s). Secondly, for each of these phases, i) we present background information on governance agencies, policies, and infrastructures conforming water governance regimes and changes therein, and ii) we describe two exemplary drought events and document related adaptation practices.

Keywords: climate change; droughts; liberalization; water governance; Spain.
ANALYSIS OF HISTORIC DROUGHTS IN THE UK: A SYSTEMS-BASED STUDY OF DRIVERS, IMPACTS AND THEIR INTERACTIONS

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An understanding of past droughts is essential for contemporary and future water management. Considerable effort has been invested in analysing historic droughts in the UK using hydrometeorological datasets, but such studies have rarely considered the socio-economic drivers and impacts of drought. This is a major gap in research, as droughts are not simply natural hazards; they emerge from the interaction between environmental drivers and impacts on the one hand, and human and societal responses on the other. Improved drought management should be developed through a more integrated perspective informed by an understanding of the links between environmental and social systems during past drought events. The ‘Historic Droughts’ project (http://www.ceh.ac.uk/our-science/projects/historic-droughts) is a joint UK Research Council funded project that aims to develop such an integrated assessment of past drought occurrence in the UK. A truly multi-disciplinary perspective is taken in order to develop an inventory of past droughts as they have manifested in different sectors, such as hydrometeorology and the environment, water resources management, agriculture, regulation and policy and citizens’ perceptions. The project embraces diverse data sources and novel methodologies to reconstruct past drought characteristics including, for example: hydrological modelling reconstructions to extend river flow and groundwater records back to the late 19th Century; assessment of water resources management interventions in past droughts using water company records; producing timelines of regulatory reform milestones through records of political debate in the House of Commons; reconstruction of agricultural impacts through proxies, e.g. crop prices; collation of oral histories based on interviews in communities affected by major past droughts; computer-aided discourse analysis of newspapers from the 19th and 20th centuries. This interdisciplinary knowledge-base is being used to develop a systems-based understanding of drought, reflecting the fact that droughts are complex hazards, a function of manifold human and natural drivers, impacts and their interactions. A better understanding of these systems interactions in past events is being used to inform improvements in management and communication of droughts in future.
The year 793 was a challenge for the Carolingian society. A famine called for adaptive strategies as hunger and mortality spread. The decrees formulated in the following year in Frankfurt may be described as an act of crisis management by Charlemagne. Comparing the legal document with other legislative texts of the time, Charlemagne’s advice indicates aspects of vulnerability and resilience of a pre-modern society. It could reveal people’s modes of adaptation to the given event. However, information on environmental circumstances that may have caused the famine is poor. Were human mismanagement, heavy rainfall or – as dendrochronological data may suggest – a drought responsible for the shortcomings?

By bringing together archives on nature and culture, this paper will discuss natural impacts and cultural responses in the late 8th century. The spatial extent of the analysis will cover Western Europe with a focus on the Carolingian realm. The paper will initially give an overview of written evidence such as annals and legal documents that refer to the famine. It will then discuss unfavorable natural impacts on the Frankish agricultural system in terms of wetness and dryness before examining data from the natural sciences concerning the time in question. Considering uncertainties in both disciplines, the paper will finally discuss modes of socioeconomic adaptation of the possible drought in the Carolingian Age.

Keywords: Environmental History, Early Middle Ages, Droughts, Vulnerability and Resilience, Dendrochronology.
Several outbreaks of locust invasions have hit Central Europe during the Late Middle Ages and in Early Modern Times. Due to their perception and interpretation as a divine punishment and a portent of the Last Judgement they are well documented in contemporary annals and chronicles as well as by frescoes and other pictorial sources.

However, the reasons why locusts occasionally change from a solitary way of life to a gregarious one by building swarms of billions of animals is still under dispute (see e.g. Anstey et al. 2009). A recent article by Brázdil et al. (2014) asked whether past locust outbreaks in the Czech Lands indicate specific climatic patterns or not. The authors concluded that there seem to be no distinct climatic features related to seasonal temperature and precipitation patterns in Central Europe during the years in which the locust outbreaks took place. However, in this presentation it is argued that an antecedent year with severe drought such as in 1473 and 1540 might have triggered the outbreak of locust invasions rather than the climatic situation in the subsequent year of the outbreak itself.

The paper will include a re-analysis of the most important documentary sources on locust invasions in Central Europe, in particular for the Eastern Alpine countries. It will be asked if the perception of those outbreaks as disasters had also been influenced by the food shortage during the drought years of 1473 and 1540.

Finally, other locust outbreaks from the Late Middle Ages up to the 20th century, both in Central Europe and in the Mediterranean region, will be considered for verifying or contradicting the principle assumption of this paper.

A paper by Chantal Camenisch regarding the drought of 1473 and a synthesis paper on several droughts during the fifteenth and the sixteenth century by Christian Pfister are linked to this presentation.

Keywords: historical climatology, drought, vulnerability, locust invasions, disaster perception.
THE 1904 GREAT DROUGHT EPISODE IN AUSTRIAN GALICIA: ADAPTATION AND RESILIENCE IN A POOR CENTRAL EUROPEAN RURAL SOCIETY

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Galicia, one of the most economically backward provinces of the Habsburg monarchy had repeatedly been being affected by various natural disasters. Next to floods, hailstorms, epidemics and fires, droughts caused substantial material losses especially to subsidence agriculture, on which nearly three quarters of the Galician population was dependent. The occurrence of droughts is characteristic of the Polish climate. During the late Habsburg period, significant droughts occurred in 1872, 1876, 1893, 1904 and 1913. They lasted for many weeks and covered considerable area. This paper focuses on the 1904 drought, which ranked as the most severe in Central Europe since 1473. Based on the analysis of various sources (daily press, scientific literature and archival records), this paper retraces drought episodes from a hydrological, agricultural and social perspective. From mid-May to the end of August 1904, almost no rain fell over the entire Galician territory. This drought took place after several years of catastrophic floods in the Vistula (1899, 1902, 1903) and Dniestr (1900) river basins. It severely affected crops and pastures causing a loss of approximately 200 million Krones for the Galician economy. One of the most serious impacts of the drought was the lack of crops and pastures for livestock. As the insurance and compensation system was at this time insufficiently developed, Galician farmers turned to the provincial and central authorities (the Galician Diet – a type of regional parliament, its executive organ; the Governor in Lwów and the organs of the central administration) for help. By investigating public reactions to the catastrophe as well as its demographic and ecological mid-term consequences, the paper questions the ability of a backward, rural Central European society to adapt to a serious drought episode in the context of repeated natural disasters.

Keywords: Austrian Galicia, Drought, Crops, Pastures, Rural economy.
THE MEMORY OF DROUGHTS – FROM WRITTEN SOURCES INTO TAMBORA’S DIGITAL SUSTAINABILITY. THE NEAR AND MIDDLE EAST CASE STUDY

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Starting in the 1980s, the data set presented here was initially collected by Prof. Dr. Heinz Grotzfeld and his working group at the University of Münster with the aim of exploring written sources of the Near and Middle East for climate reconstruction. In the framework of this project, several thousand sources relevant to climatology and environmental history were acquired. These are mainly based on chronicles and annals, a genre that was established in the Orient since the 8th century, mainly by scholars and historians.

This unique data set consisting mainly of hand-written paper-based file cards was transferred into tambora.org, a collaborative research environment for digital sustainable data storage that enables translation, codification and derivation of indices as well as visualization, dissemination and publication. This workflow will be presented in addition to first results from case studies based on similar types of data and analyses.

Firstly, the file cards were digitized. German, English or Arabian handwritten entries were transferred into a word processing program and consistently translated into German. To enable a correct temporal codification of the data, date specifications were converted into the Gregorian calendar.

Secondly, the acquired sources were evaluated source-critically following hermeneutic principles to ensure their reliability and enable extraction of useable insights. In doing so, existing source-critical approaches were used. Data were iteratively controlled and coded following the existing coding scheme of tambora.org to ensure an optimized and consistent set. The coding process finally results in an information set covering time, location and content-index. Most of the data are related to temperature and precipitation and within this context also to droughts, dust storms, harvest failures and phenological information but they also include societal reactions and interpretations.

The time series derived from the data are presented. The data set and some of the relevant codes and indices are published and citable via DOIs.

Keywords: Near and Middle East, tambora.org, collaborative research environment, workflow